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(54) Abstract Title  
**Method of discharge for plurality of series connected rechargeable batteries**

(57) When a plurality of series connected rechargeable batteries (1) are discharged, they have the remaining capacity of each battery measured by a detection circuit (5), and the battery with the lowest capacity is determined. The output of the series of batteries is then reduced to the battery voltage, e.g. by DC-DC converter (2), and supplied to the battery with lowest capacity. This equalizes the voltage level of each of the plurality of batteries ready for recharging. In a further embodiment the capacity of the batteries is measured and equalized during discharge. The capacity of the batteries may be determined by measuring voltage.

**FIG. 1**

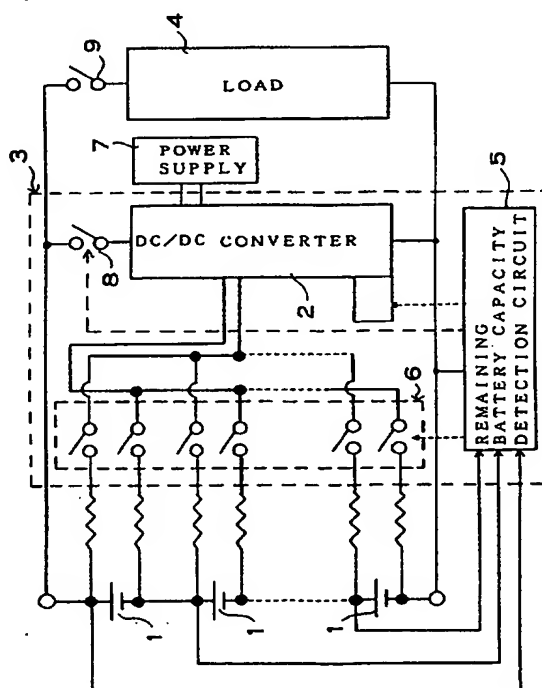
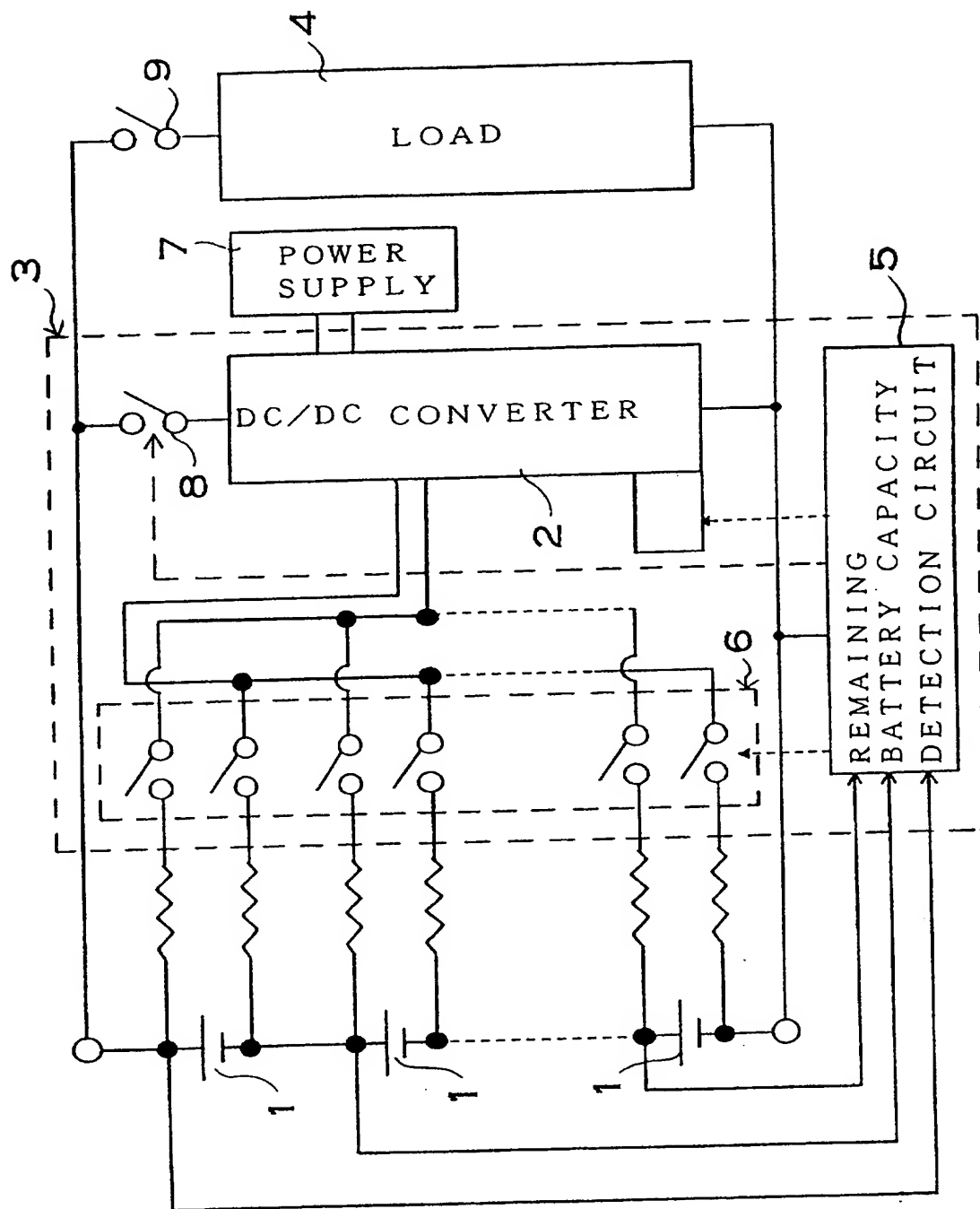


FIG. 1



Method of Discharge for a Plurality of Rechargeable Batteries, and Battery  
Assembly

This application is based on application No. 11-216178 filed in Japan on  
5 July 30, 1999, the content of which incorporated hereinto by reference.

BACKGROUND OF THE INVENTION

The present invention relates to a discharge method which can efficiently  
10 discharge a plurality of rechargeable batteries, and to a battery assembly  
containing a discharge control circuit which discharges batteries according to  
this discharge method.

A battery assembly can output high voltages by connecting a plurality of  
rechargeable batteries in series. When this battery assembly supplies power to  
15 a load, the same current flows through all the rechargeable batteries. For this  
reason, if the capacities of all the batteries are not equal, i.e. unbalanced, the  
remaining battery capacity of a low capacity battery will become smaller than  
that of a high capacity battery. As a result, when the high capacity battery  
becomes completely discharged, the low capacity battery has already over-  
20 discharged. This problem can be overcome by stopping battery assembly  
discharge when the low capacity battery becomes completely discharged.  
However, when battery assembly discharge is stopped in this fashion, the total  
power output from the entire battery assembly is limited by the battery with the  
lowest battery capacity.

25 This problem would not occur if the battery assembly could be charged  
and discharged in a manner that created no battery capacity imbalance among  
any of the rechargeable batteries. However, connecting a plurality of  
rechargeable batteries in series and keeping all battery capacities equal at all  
times is, for practical purposes, utterly impossible. As charging and discharging  
30 is repeated, the battery capacities of a plurality of series connected

rechargeable batteries have the tendency to become more unbalanced.

The imbalance between individual batteries of a battery assembly becomes more of a problem as the number of series connected batteries increases. For example, in a battery assembly with 100 rechargeable batteries connected in series, keeping all rechargeable batteries in the same charge capacity state while charging and discharging repeatedly, is extremely difficult. For such a battery assembly, electrical performance of the system is significantly degraded if the capacity of even one battery is low. This is because the power which can be output by the battery assembly is relatively low when discharge is stopped to prevent over-discharge of the low capacity battery as described above. On the other hand, if discharge is continued to increase battery assembly output until the low capacity battery is over-discharged, the efficiency of that battery rapidly deteriorates and the performance of the battery assembly as a system is degraded.

As a solution to this problem, a battery assembly provided with an auxiliary battery, separate from the series connected batteries, was developed. In this battery assembly, the remaining battery capacity of each battery is measured during discharge, and power is supplied from the auxiliary battery to the battery with the lowest remaining battery capacity. Since the battery with the lowest remaining battery capacity is supplied with power from the auxiliary battery, over-discharge is prevented. Therefore, total battery assembly output is increased while preventing over-discharge of the low capacity battery.

Although a battery assembly provided with an auxiliary battery can prevent over-discharge of the low capacity battery, it is necessary to include an additional auxiliary battery which is not used at all times. Consequently, as the size of the battery assembly increases, manufacturing cost increases, and since the auxiliary battery is not used at all times, the battery assembly has the drawback that the auxiliary battery cannot be used efficiently. This battery assembly has the further drawback that over-discharge of the low capacity battery cannot be prevented if auxiliary battery capacity becomes low. The

lifetime of the auxiliary battery may not always be greater than the lifetimes of all the batteries comprising the battery assembly.

Further, selection of the battery capacity for the auxiliary battery is extremely difficult. The purpose of the auxiliary battery is to compensate for battery capacity imbalance between a plurality of rechargeable batteries and prevent over-discharge of the low capacity battery. As battery capacity imbalance increases, a higher capacity auxiliary battery is required. However, the imbalance between individual batteries is definitely not fixed and varies widely depending on the battery assembly. If auxiliary battery capacity is made large to reliably compensate for battery capacity imbalance, over-discharge of the low capacity battery can effectively be prevented, but auxiliary battery utilization efficiency becomes worse. In contrast, if auxiliary battery capacity is made small, the auxiliary battery cannot reliably prevent over-discharge of the low capacity battery.

The present invention was developed to eliminate these types of drawbacks associated with prior art battery assemblies. Thus, a primary object of the present invention is to provide a method of discharge for a plurality of rechargeable batteries and a battery assembly which discharges according to that method wherein over-discharge of the low capacity battery can be prevented and the total output of the battery assembly can be increased without using an auxiliary battery.

The above and further objects and features of the invention will more fully be apparent from the following detailed description with accompanying drawings.

## SUMMARY OF THE INVENTION

The discharge method of the present invention is a method of discharge for a plurality of series connected rechargeable batteries wherein the remaining battery capacity of each discharging rechargeable battery is measured, and

discharge proceeds while battery voltage stepped down from the output voltage of a plurality of series connected rechargeable batteries is supplied to a rechargeable battery determined to have low remaining battery capacity.

5 In this discharge method, remaining battery capacity can be determined by measuring the voltage of each rechargeable battery. The remaining battery capacity of a rechargeable battery with reduced battery voltage is judged as low, and thus the low capacity rechargeable battery can be discriminated.

10 In the discharge method of the present invention, output voltage from the series connected rechargeable batteries is converted to a battery level voltage by a DC/DC converter, and this voltage can be supplied to the low capacity rechargeable battery. The DC/DC converter reduces voltage from a level capable of charging the low capacity rechargeable battery to a level which reduces low capacity rechargeable battery discharge current. DC/DC converter output voltage is supplied to the low capacity rechargeable battery.

15 DC/DC converter output voltage can be changed depending on the remaining battery capacity of the low capacity rechargeable battery.

Further, the battery assembly of the present invention contains a plurality of series connected rechargeable batteries and a discharge control circuit to control the discharge state of the rechargeable batteries. This battery assembly  
20 discharges a plurality of series connected rechargeable batteries to supply power to a load. In addition, this battery assembly has a discharge control circuit provided with a remaining battery capacity detection circuit to measure the remaining battery capacity of each rechargeable battery and determine the low capacity rechargeable battery, a DC/DC converter to step down the output  
25 voltage of a plurality of series connected rechargeable batteries to a battery level voltage, and switching circuitry to supply DC/DC converter output to the low capacity rechargeable battery. This battery assembly discharges while supplying output voltage, from a plurality of rechargeable batteries converted to battery level voltage by the DC/DC converter, to a rechargeable battery  
30 determined to have low remaining battery capacity by the remaining battery

capacity detection circuit.

In this battery assembly, DC/DC converter output voltage can be changed depending on the remaining battery capacity of the low capacity rechargeable battery.

5       The above discharge method, and battery assembly utilizing that discharge method for discharging rechargeable batteries have the outstanding feature that over-discharge of each rechargeable battery can be prevented while total output can be increased, even though an auxiliary battery is not used. This is because a rechargeable battery with low battery capacity, which  
10       has the possibility of being over-discharged, is determined to be the low capacity rechargeable battery, and power is supplied to this low capacity rechargeable battery from the other batteries.

      A discharge method and battery assembly with many series connected rechargeable batteries, which can discharge without over-discharging any  
15       individual battery, can not only increase battery assembly total power output, but can also extend the life of the rechargeable batteries. This discharge method and battery assembly have the exceptional characteristic that each rechargeable battery can be discharged under ideal, balanced conditions. This characteristic is extremely important for a battery assembly, such as an  
20       automobile battery assembly, which has a large number of series connected batteries. This is because the probability that one rechargeable battery will degrade increases in proportion to the number of batteries in a battery assembly with many series connected rechargeable batteries, and if a battery degrades, the entire battery assembly becomes unusable. Further, since the  
25       overall cost of a battery assembly with many series connected rechargeable batteries is extremely high, long usable lifetime is important. Nevertheless, if any rechargeable battery in this type of battery assembly degrades and becomes unusable, the many other rechargeable batteries, which are in usable condition, become unusable. Therefore, in a battery assembly with many series  
30       connected rechargeable batteries, how ideal the discharge conditions of each

rechargeable battery are is of utmost importance.

Moreover, the discharge method and battery assembly described above do not prevent over-discharge of a degraded rechargeable battery via an auxiliary battery. Over-discharge of a degraded rechargeable battery is prevented via the other non-degraded rechargeable batteries. For this reason, there is no need to provide an auxiliary battery. Consequently, there is no need to control auxiliary battery charge and discharge, and the feature that all rechargeable batteries can be discharged under ideal, balanced conditions is realized.

## BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1. is a block diagram of the battery assembly used in the discharge method of the present invention.

## DETAILED DESCRIPTION OF THE INVENTION

The battery assembly shown in Fig. 1 contains a plurality of series connected rechargeable batteries 1 and a discharge control circuit 3 to control the state of discharge of the rechargeable batteries 1. The battery assembly discharges the plurality of series connected rechargeable batteries 1 to supply power to a load 4. The rechargeable batteries 1 are lithium ion rechargeable batteries. However, rechargeable batteries 1 may also be nickel hydrogen batteries, nickel cadmium batteries, or some other type of rechargeable batteries. The number of rechargeable batteries in the battery assembly varies depending on the application. The battery assembly may be used to drive a motor to power an automobile, or it may be used as the power source for a personal computer. A battery assembly for driving an automobile motor may have 100 to 300 rechargeable batteries connected in series.

The discharge control circuit 3 is provided with a remaining battery



capacity detection circuit 5 to measure the remaining battery capacity of each rechargeable battery 1 and determine the low capacity battery, a DC/DC converter 2 to reduce the output voltage of the plurality of series connected rechargeable batteries 1 to a battery level voltage, and switching circuitry 6 to supply DC/DC converter 2 output to the low capacity rechargeable battery.

The remaining battery capacity detection circuit 5 measures remaining battery capacity by measuring the voltage of each rechargeable battery 1. The remaining battery capacity detection circuit 5 sequentially measures the voltage of each rechargeable battery 1, judges batteries with reduced voltage to have low remaining battery capacity, and determines the low capacity battery. A remaining battery capacity detection circuit 5 which determines remaining battery capacity from battery voltage can be a simple detection circuit. However, the remaining battery capacity detection circuit 5 can also integrate charging current and discharge current, in addition to measuring battery voltage to determine remaining battery capacity.

The remaining battery capacity detection circuit 5 determines the rechargeable battery 1 with the lowest remaining battery capacity or with remaining battery capacity below a prescribed level as the low capacity battery. A remaining battery capacity detection circuit 5 which determines remaining battery capacity from battery voltage determines the rechargeable battery 1 with the most reduced voltage or with voltage which has dropped below a prescribed level as the low capacity battery. The remaining battery capacity detection circuit 5 is connected to each rechargeable battery 1, and is sequentially switched to read the voltage of each rechargeable battery 1 and determine remaining battery capacity.

The remaining battery capacity detection circuit 5 controls the switching circuitry 6 to supply battery voltage output from the DC/DC converter 2 to the low capacity battery. The remaining battery capacity detection circuit 5 controls the switching circuitry 6 to connect the low capacity rechargeable battery to the output side of the DC/DC converter 2 and disconnect all other rechargeable

batteries 1 from the output side of the DC/DC converter 2.

5 The DC/DC converter 2 converts the output voltage of the plurality of series connected rechargeable batteries 1 to alternating current (AC) via switching, reduces the AC voltage via a transformer, and converts the AC to direct current (DC) for output. DC/DC converter 2 output voltage can be a constant battery level voltage, or it can vary according to the remaining battery capacity of the low capacity battery. DC/DC converter 2 output voltage is set to a voltage which can charge the low capacity battery while in the discharge mode, or is set to a voltage which cannot charge the low capacity battery but  
10 can reduce its discharge current or make it zero. In a DC/DC converter 2 which varies its output voltage according to the remaining battery capacity of the low capacity battery, output voltage is increased as remaining battery capacity of the low capacity battery decreases, and is reduced as remaining battery capacity increases.

15 In a battery assembly with DC/DC converter 2 output voltage capable of charging the low capacity battery, the remaining battery capacity of the low capacity battery can be made equal to that of the other rechargeable batteries 1 in a short period because the other rechargeable batteries 1 are discharged while the low capacity battery is charged. In a battery assembly with DC/DC  
20 converter 2 output voltage not capable of charging the low capacity battery but capable of reducing its discharge current or making the discharge current zero, all rechargeable batteries 1 can be discharged while preventing over-discharge of the low capacity battery. In particular, for a battery assembly with DC/DC converter 2 output voltage set to make the low capacity battery discharge  
25 current zero, the low capacity battery can be a completely discharged rechargeable battery. By supplying battery level voltage from the DC/DC converter 2 to this low capacity battery, the battery assembly can be discharged while preventing over-discharge of the low capacity battery.

30 In a battery assembly with many rechargeable batteries connected in series, a plurality of rechargeable batteries 1 can be designated as low

capacity batteries prior to complete discharge, and battery voltage from the DC/DC converter 2 can also be supplied to these batteries. The output voltage of the DC/DC converter 2 of this battery assembly is set to a voltage greater than that which reduces the discharge current of the low capacity batteries to zero. The output voltage of the DC/DC converter 2 for this battery assembly is set between a voltage which charges the low capacity batteries and a voltage which reduces their discharge current. Preferably, the output voltage of the DC/DC converter 2 for this battery assembly is set to a voltage which can charge the low capacity batteries. This is because power supplied from the DC/DC converter 2 to a rechargeable battery 1 designated as the low capacity battery can quickly bring the remaining battery capacity of that low capacity battery into balance with the other rechargeable batteries 1. In this battery assembly, when the remaining battery capacity of any one of the rechargeable batteries 1 becomes low and that battery is designated the low capacity battery, battery voltage is supplied to that battery to bring its remaining battery capacity into balance with the other rechargeable batteries 1. Next, when the remaining battery capacity of a different rechargeable battery 1 becomes low and that battery is designated the low capacity battery, battery voltage is then supplied to that battery to bring its remaining battery capacity into balance with the other rechargeable batteries 1. Consequently, prior to complete discharge of the battery assembly, a plurality of rechargeable batteries 1 are determined to be the low capacity battery and are supplied with power from the DC/DC converter 2 to balance remaining battery capacities during discharge.

The switching circuitry 6 connects the positive and negative terminals of each rechargeable battery 1 with the positive and negative output terminals of the DC/DC converter 2 to independently connect each rechargeable battery 1 to the output side of the DC/DC converter 2. In this switching circuitry 6, switching devices are connected between the DC/DC converter 2 and the rechargeable batteries 1. The switching devices are field effect transistors (FETs), but they may also be (bipolar) transistors. Further, in the switching

circuitry 6 of Fig. 1, protection resistors are connected in series with the switching devices.

Switching circuitry 6 switching devices connected to the positive and negative terminals of a rechargeable battery 1 form a pair, and each pair is controlled on and off by the remaining battery capacity detection circuit 5. When the remaining battery capacity detection circuit 5 switches any one pair of switching devices on, it turns all other switching devices off. This is to supply battery voltage from the DC/DC converter 2 to a single low capacity battery.

The battery assembly shown in Fig. 1 is charged and discharged in the following manner.

(1) The battery assembly is charged to full capacity. Battery assembly series connected rechargeable batteries 1 are individually charged to full capacity in sequence, or they are charged to full capacity while connected together in series. The method of fully charging individual rechargeable batteries 1 in sequence has the feature that each battery can be fully charged without over-charging. A power supply 7 is connected to the DC/DC converter 2 of Fig. 1. Charging voltage from the power supply 7 is supplied to each rechargeable battery 1 to fully charge each battery in sequence, or is supplied to the series connected rechargeable batteries 1 to fully charge all batteries together. For an automobile battery assembly, the power supply 7 is a generator/alternator. In a battery assembly for household electronics, such as a personal computer (PC), the power supply 7 is a device such as an AC adapter.

A battery assembly which sequentially charges each individual rechargeable battery 1 can utilize the switching devices of the switching circuitry 6 for charging. In a battery assembly which charges all series connected rechargeable batteries 1 together, the switching circuitry 6 switching devices are turned off, and rechargeable batteries 1 are charged by power from the DC/DC converter 2 supplied from the power supply 7. At this time, for the battery assembly shown in Fig. 1, the charging switch 8, which connects the DC/DC converter 2 in series with the rechargeable batteries 1, is turned on.

(2) When the battery assembly is discharged, the discharge switch 9, connected between the battery assembly and the load 4, is switched on. At this time, all of the rechargeable batteries 1 contained in the battery assembly supply power to the load 4 in a series connected configuration. The voltage of the battery assembly is equal to the number of rechargeable batteries 1 times the battery voltage.

(3) When the rechargeable batteries 1 are discharged, the remaining battery capacity detection circuit 5 of the discharge control circuit 3 measures the voltage of each rechargeable battery 1 to determine remaining battery capacity

The rechargeable battery 1 with the lowest remaining battery capacity or with capacity below a prescribed value is designated as the low capacity battery, and switching devices connected to the positive and negative terminals of the low capacity battery are switched on while all other switching devices remain in the off state.

Immediately after discharge is started, the remaining battery capacity detection circuit 5 determines rechargeable battery 1 remaining battery capacity and designates the rechargeable battery 1 with either the lowest remaining battery capacity or with remaining battery capacity below a set capacity as the low capacity battery.

In a discharge method which determines the low capacity battery immediately after discharge is started and supplies battery voltage from the DC/DC converter 2 to that low capacity battery, DC/DC converter 2 output can be reduced and over-discharge of the low capacity battery can be prevented. This is because the DC/DC converter 2 supplies power to the low capacity battery over a long time period.

In a method which determines a low capacity battery with remaining battery capacity lower than a prescribed capacity and supplies battery voltage from the DC/DC converter 2 to that low capacity battery, it is not necessary to supply battery voltage from the DC/DC converter 2 immediately after starting discharge of the fully charged battery assembly. During battery assembly

discharge, when the remaining battery capacity of any rechargeable battery 1 drops below the prescribed capacity, and it is judged that the low capacity battery will over-discharge if this condition persists, this low capacity battery is either charged or its discharge current is reduced by supplying battery voltage from the DC/DC converter 2.

In either discharge method, battery voltage is supplied from the DC/DC converter 2 to the rechargeable battery 1 designated the low capacity battery. When the remaining battery capacity of the designated low capacity battery becomes greater than that of the other rechargeable batteries 1 or greater than a prescribed battery capacity, the switching devices connected to that low capacity battery are switched off and power supply from the DC/DC converter 2 is stopped.

(4) Subsequently, the remaining battery capacity of each rechargeable battery 1 is measured and when the battery with the lowest remaining battery capacity or with capacity below the prescribed capacity is determined, step (3) is repeated, the low capacity battery is connected to the DC/DC converter 2, and battery assembly discharge is performed while preventing over-discharge of the low capacity battery.

As this invention may be embodied in several forms without departing from the spirit of essential characteristics thereof, the present embodiment is therefore illustrative and not restrictive, since the scope of the invention is defined by the appending claims rather than by the description preceding them, and all changes that fall within the meets and bounds of the claims, or equivalence of such meets and bounds thereof are therefore intended to be embraced by the claims.

What is claimed is:

1. A method of discharge for a plurality of series connected rechargeable batteries comprising the steps of:

5       measuring remaining battery capacity of each rechargeable batteries being discharged;

      detecting a rechargeable battery with low capacity, the battery determined to have low remaining battery capacity;

      reducing a battery voltage supplied from the plurality of series connected  
10    rechargeable batteries; and

      discharging each of rechargeable batteries, supplying the reduced voltage to the low capacity rechargeable battery.

15    2. A method of discharge for a plurality of rechargeable batteries as recited in claim 1 wherein the voltage of each rechargeable battery is measured to determine the remaining battery capacity.

20    3. A method of discharge for a plurality of rechargeable batteries as recited in claim 1 wherein the series connected rechargeable batteries are individually charged to full capacity in sequence.

25    4. A method of discharge for a plurality of rechargeable batteries as recited in claim 1 wherein the output voltage from the plurality of series connected rechargeable batteries is converted to a battery charging voltage via a DC/DC converter.

30    5. A method of discharge for a plurality of rechargeable batteries as recited in claim 4 wherein DC/DC converter output voltage is varied depending on the remaining battery capacity of the low capacity rechargeable battery.

6. A method of discharge for a plurality of rechargeable batteries as recited in claim 4 wherein DC/DC converter output voltage is a fixed voltage.

7. A method of discharge for a plurality of rechargeable batteries as recited in claim 4 wherein DC/DC converter output voltage is a voltage capable of charging the low capacity rechargeable battery

8. A method of discharge for a plurality of rechargeable batteries as recited in claim 4 wherein DC/DC converter output voltage is set to a voltage not capable of charging the low capacity rechargeable battery, but capable of reducing its discharge current.

9. A method of discharge for a plurality of rechargeable batteries as recited in claim 4 wherein DC/DC converter output voltage is set to a voltage not capable of charging the low capacity rechargeable battery, but capable of making its discharge current zero.

10. A method of discharge for a plurality of rechargeable batteries as recited in claim 4 wherein DC/DC converter output voltage is raised when low capacity rechargeable battery remaining battery capacity decreases, and is lowered when remaining battery capacity increases.

11. A method of discharge for a plurality of rechargeable batteries as recited in claim 4 wherein, prior to complete discharge of a battery assembly, a plurality of rechargeable batteries are determined to be low capacity rechargeable batteries, and rechargeable batteries determined to be low capacity rechargeable batteries are sequentially charged by DC/DC converter output.

12. A battery assembly which supplies power to a load comprising:

(a) a plurality of series connected rechargeable batteries;



(b) a discharge control circuit to control the state of rechargeable battery discharge and having;

- (1) a remaining battery capacity detection circuit to measure the remaining battery capacity of each rechargeable battery and determine a low capacity rechargeable battery;
- (2) a DC/DC converter to reduce the output voltage from the plurality of series connected rechargeable batteries to a battery voltage;
- (3) switching circuitry to supply DC/DC converter output to the low capacity rechargeable battery; and wherein

10 (c) discharge is performed while output from the plurality of series connected rechargeable batteries is converted to a battery voltage by the DC/DC converter and is supplied to the low capacity rechargeable battery determined to have low remaining battery capacity by the remaining battery capacity detection circuit.

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13. A battery assembly as recited in claim 12 wherein the DC/DC converter varies its output voltage depending on the remaining battery capacity of the low capacity rechargeable battery.

20 14. A battery assembly as recited in claim 12 wherein DC/DC converter output voltage is a fixed voltage.

15. A battery assembly as recited in claim 12 wherein DC/DC converter output voltage is a voltage capable of charging the low capacity rechargeable battery

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16. A battery assembly as recited in claim 12 wherein DC/DC converter output voltage is set to a voltage not capable of charging the low capacity rechargeable battery, but capable of reducing its discharge current.

30 17. A battery assembly as recited in claim 12 wherein DC/DC converter output

voltage is set to a voltage not capable of charging the low capacity rechargeable battery, but capable of making its discharge current zero.

5 18. A battery assembly as recited in claim 12 wherein DC/DC converter output voltage is raised when low capacity rechargeable battery remaining battery capacity decreases, and is lowered when remaining battery capacity increases.

10 19. A battery assembly as recited in claim 12 wherein the discharge control circuit contains a charging circuit which sequentially charges individual series connected rechargeable batteries to full capacity.

15 20. A battery assembly as recited in claim 12 wherein the switching circuitry has switching devices independently connecting the positive and negative terminals of each rechargeable battery to the positive and negative output terminals of the DC/DC converter.

21. A battery assembly as recited in claim 20 wherein the switching circuitry has protection resistors connected in series with the switching devices.

22. A method of discharge for a plurality of series connected rechargeable batteries substantially as hereinbefore described with reference to the accompanying drawings.

23. A battery assembly substantially as hereinbefore described with reference to the accompanying drawings.